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/This article explains the basic elements and operation of electronic computers of discrete (flip-flop, or digital) action. The following is an extract translation; the full table of contents with the translated sections marked by an asterisk is presented directly below/.

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~~1.~~ Introduction

Present-day mathematical machines can be divided into two large classes: machines of continuous action (i.e. analog machines); and machines of discrete counting, or numerical ('cipher') machines (i.e. digital machines).

Machines of continuous action (i.e. analogs) are characterized by the fact that the variables entering the mathematical problem to be solved are represented by definite physical quantities (such as the angle of turn of mechanical shafts, electric currents, voltages, etc) which pass continuously through all the values of the variables in the solution area. Such a machine consists of a large number of physical devices of several types in which ~~(devices)~~ the mentioned physical quantities are subjected to transformations corresponding to definite mathematical operations; for example, addition, multiplication, integration, differentiation, [redacted], etc. The adjustment of the machine to a given mathematical problem consists of [redacted] joining these physical devices in correspondence with the equations written down, but the solution is obtained from the machine by [redacted] measuring definite physical quantities corresponding to the desired variables. To machines of continuous action belong the differential analyzer and electronic amplifier systems for solving ordinary differential equations.

Machines of discrete counting operate with numbers represented in cipher form and automatically execute a given sequence of the four arithmetical operations (addition, subtraction, multiplication, division) and make selections from tables. The solution of any mathematical problem involving finite calculations leads namely to these elementary operations. Here the problem is solved not continuously, but discretely in a definite number of steps. On the other hand, numerical solutions of present-day problems in the natural sciences require the preparation of tremendous number of such elementary operations with many significant figures. Therefore such machines must be high-speed and automatic to a high degree. /Note: Hereafter, "machines of discrete counting" will be called "~~discrete~~ digital machines", for simplicity./

~~Discrete~~ Digital machines in comparison with machines of continuous action suffer the following deficiencies: 1) great complexity; 2) necessity for a detailed mathematical preparation of the problem in the form of a sequence of arithmetical operations; the discreteness or discontinuity of the solving process hinders ~~one's~~ the utilization of machines in joint operation with real active objects.

Together with these deficiencies, however, the automatic ~~discrete~~ digital machine possesses a whole series of advantages in solving problems, such as: 1) complete universality in the sense that any mathematical problem can be solved; 2) unlimited accuracy which is determined in finite calculations by the number of divisions, or places, in the counter; that is, by the number of significant figures with which the machine can operate.

It is necessary to keep in mind that the accuracy of ~~discrete~~ digital machines depends both upon the accuracy of operation in the physical devices which are modeling definite mathematical operations and upon the accuracy of measurement of these same physical quantities, and does not exceed 4 or 5 figures.

As for ~~discrete~~ digital machines, in consequence of the very principle of counting, it is required of physical devices, as employed in this or that class of counters, only that they possess several (in the simplest case, two) clearly expressed discrete states — the devices themselves can be rather crude. For example, electron tubes that are used in the mathematical circuits of continuous-action machines (i.e. analog machines) limit in practice the accuracy of these machines by several percent because of the instability of the electron tube's characteristic. But in ~~discrete~~ digital machines this does not matter since here all that is required of the electron tube is that it have two states - the current flows or the current does not flow ("yes" - "no"), the accuracy of the machine depending exclusively on the number of divisions in the counter. In this way high-accuracy machines can be assembled from such very inaccurate elements of mass production as electron tubes (the scatter of their characteristics reaches 40%).

In electronic ~~discrete~~ digital machines, both ciphers (numbers) and commands, which determine the necessary operations to be executed at a given moment of time, are transmitted in the form of electric pulses with a duration ("width") of the order of several microseconds (for greater detail see below) and with a magnitude ("height") of several decavolts; ~~whereupon,~~ the value of this or that number or command is essentially determined not by the magnitude of the pulses but by their quantity. Thus, for example, if the machine operates on the decimal system, then the cipher 3 corresponds to three pulses etc. Besides such "dynamical" representation of ciphers in the form of a definite sequence of electrical pulses, there also takes place in electronic instruments the so-called "static" representation in the form of a variation in state of this or that element; for example, the transition of an electron tube from the nonconducting to the conducting state, the hook-up of electronic relays, etc.

The electronic digital machine consists of the following fundamental blocks: counters for execution of mathematical operations; memory apparatus ("the memory") for the retention of intermediate results of calculation; input of the necessary tables of functions etc; input and output devices; and also the block that controls the execution of the automatic sequence of operations (program control, or direction). These blocks are not always electronic; for mechanical and electromagnetic devices are also widely employed here, so long as the employment of these comparatively slow devices does not essentially decrease the high speed of electronic calculation. For example, the memory installation can be made in the form of a combination of: fast-acting electronic memory of limited capacity, in which data that is often utilized in the calculation process is remembered; and electromagnetic (relay) memory or even memory in the form of punched tapes or cards, whose capacity is unlimited and where data can be remembered which is seldom encountered in the calculational sequence.

As for purely electronic devices and memories, they can be utilized either statically or dynamically.

In the first electronic calculators the counters were utilized both for calculation and for memory (accumulators), in consequence of which the memory capacity of such machines was greatly limited (up to 20 ten-place numbers). In present-day machines the functions of calculation and memory are separate and each of them is effected by separate devices. As a result it turned out to be possible to have in all several counters and a very extensive electronic memory of several thousand ten-place numbers.

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As opposed to manual practice in calculating, in electronic ~~discrete~~ digital machines the decimal system is not the sole one. The binary system is in wide use; in it each number is represented in the form of a sum of powers of two. Thus the number 37 is represented in the binary system thus:

$$37 = 1\cdot2^5 + 0\cdot2^4 + 0\cdot2^3 + 1\cdot2^2 + 0\cdot2^1 + 1\cdot2^0, \text{ or } 100\ 101.$$

Thus the cipher of each division, or place, is either 0 or 1. This property of the binary system is exceptionally valuable, since it makes possible in a very easy way the storage of a great number of ciphers in the memory. Thus, each place in a binary number can be remembered by any element having two stable states ("yes" - "no "), corresponding to 0 and 1. This can be the conducting or nonconducting state of the electron tube, the absence or presence of a charge in a small capacitor (static memory), the absence or presence of an electric pulse at a given mement of time (dynamic memory). Another important property of the binary system is the ability to execute in a simple way the operation of multiplication in connection with the absence, in this system, of a multiplication table. Actually, since the cipher of each division is 0 or 1, the multiplication by a given division consists of a repetition (at the corresponding division's position) of the multiplicand or of a transition to the following division of the multiplier. For example, the multiplication of 14 x 5 in the binary system is carried out in the following manner:

$$\begin{array}{rl} 1110 & (= 14) \\ \times\ \underline{101} & (= 5) \\ 1110 & \\ \underline{11100} & \\ 1000110 & \text{or } 1\cdot2^6 + 1\cdot2^2 + 1\cdot2^1 = 70 \end{array}$$

Consequently, in operations with the binary system multiplication can be effected by means of ordinary adding counters that are supplied with the proper directions; thus multiplication tables are not needed.

The third advantage of the binary system is the fact that the circuits themselves for electronic calculation in this system are simple in comparison with those using the decimal system and the number of electron tubes

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required for this circuit turns out to be less, inspite of the fact that the number of divisions (places) needed in the binary system is approximately three times as great as in the decimal system.

Actually, in a system of calculation a minimum number of elements is required such that all the numbers from one to a certain number A are possible. Let the number of ciphers in a division for a given system of counting be n (the base, or radix, of the system) and let the maximum number of divisions be p; that is, $A = n^p$. Let one element (for example, one trigger mesh. See below.) be necessary for realizing each cipher. Then the necessary number of elements will equal $N = n \cdot p$. Seeking the minimum N under the condition $A = n^p$ (with $N = n \cdot p$), we easily obtain that $n = e = 2.718$ corresponds to minimum N, in consequence of which it is necessary to set $n = 2$ or $n = 3$. For example, to realize numbers up to 10^6 in the decimal system we would require 60 elements; in the binary system, 40 and in the ternary, 38. The ternary system, although it requires the least number of elements for calculation, is much less convenient than the binary, since here three positions and not two would correspond to each division. The binary in comparison with the decimal system gives an economy of elements 1.5 times. (In practice an economy of 3 times can be attained since in the binary system one element can be used for the representation of two ciphers according to the system "yes" - "no").

It is also possible to employ a composite "binary-decimal system", where the number is laid out on the divisions according to the decimal system, but the cipher of each division is expressed according to the binary system. For example, the number 6 is represented in this system as (0110) and the number 86 is expressed as (1000), (0110) where the first parentheses are in the ten's place, written in the binary system, and the second parentheses are in the unit's place. Here the properties of both the decimal and the binary systems are mixed. For example, this system is like the binary system in its simplicity of operation with addition and multiplication and its "memory". The number of elements in the counter circuit here is somewhat greater (for example, 48 elements are necessary to realize all the numbers up to 10^6); however, this latter fact is not decisive, since the "specific gravity" of the counters (in the sense of the amount of equipment) is not considerable in comparison with the memory blocks and operation controls.

1. 4 Memory Cells; Valves; Separator Circuit

As we have already noted, in electronic machines of discrete calculation a cipher or command of the program control is transmitted with the aid of electrical pulses. If the block that "perceives" the pulses is based on a static principle, then the fact of its receiving these pulses should reflect in the block's variation of state; that is, the block should possess static electronic memory. One of the most widely used elements of static memory is the memory cell (Figure 1. Note: all figures are attached in the appendix), which consists of two triodes (electron tube with three electrodes - cathode, grid, anode) and possesses two stable states. In one stable state the left triode conducts a current, but right one does not. An opposite picture corresponds to the other state. (Note: Such a cell is often called in radar literature a trigger). Actually, let the left tube conduct a current; then in consequence of the voltage drop in its load resistance R_1 the potential of the tube's anode will be low, but the voltage on the grid of the right triode, which is connected to the anode of the left one through the resistance R_3, will be lower than the voltage of the cut-off (the minimum voltage on the tube's grid, for which an anodic current appears). The right triode appears to be closed ("Locked"). In view of the fact that the current through the right triode does not pass, the potential of its anode will be high (in consequence of the absence of the voltage drop in the resistance R_2); but, consequently, in the grid of the left triode that is connected to the anode of the right resistance R_4 there is a high voltage which maintains the conducting state of the left tube.

Transition to the other stable state can be effected by way of an input of positive pulse to the grid of the right tube. Whereupon the voltage on the anode of the right tube sharply falls. This negative pulse (voltage drop) is transmitted (mainly through the capacitor C_1, which presents for the sharp pulse a very small resistance in comparison with R_4) to the grid of the left tube, which is closed; in consequence of this the voltage on its anode is increased and consequently the potential of the grid of the right tube increases, which maintains the new stable state. The memory cell has been rendered "thrown over" to a new state equilibrium. Note that the resistances R_3 and R_4 serve to "restrain" the stable state, since in the static state the impedance of the capacitors C equals infinity in the time that the capacitors C serve to "throw over" the cell from one state to the other. The greater these capacitors, the more sharply the throw-over turns out to be. However, the magnitude of these capacitors cannot be too great: it is limited by the time required by the cell in preparation to receive the new pulse; that is, the time constant $R_3C_3 = R_4C_1$ must be considerably less than the interval between the successively incoming pulses. Ordinarily one takes $C_1 = C_2 = 20$ to 25 micromicrofarads and $R_3 = R_4 = 47000$ to 51000 ohms (for tube 6N8). Whereupon the transition from one stable state to the other proceeds in the course of about one microsecond, but the cell remains ready to receive a new pulse in 4 microseconds. This time can be significantly compressed by the employment of tubes with great sharpness [steep characteristic], ~~(steepness)~~, as for example the 6AK5 etc. Actually, there are not two tubes, but one, the so-called binary triode, which is essentially two triodes placed in one container.

Thus the entry of a pulse into one of the inputs of the trigger cell is remembered in the form of a throw-over of the cell of one stable state to the other; that is, in the form of a voltage increase or drop at the static output (Figure 1). If we connect an indicator, say a neon lamp, to any static output, then the pulse will be visually remembered in the form of its glowing (or extinguishing). In Figure 1, the input pulses are supplied to the grids of the tubes. However, they can be successfully supplied to the anodes of the tubes or to the cathodic circuits. In Figure 2 is shown one practical circuit scheme of a memory cell (on a binary triode 6N1P), where the conducting half of the tube is hatchured. Here a negative displacement to the tubes' grids (relative to the cathode) is effected because of the voltage drop in a resistance of 10,000 ohms, which is in the circuit of the cathode of the 6N1P tube.

Another important element is the electronic valve (tube) which effects the hookup of this or that circuit under the action of a special controlling electrical pulse. The simplest valve for positive pulses is the electron tube with two control grids (for example, pentagrid 6A15B, Figure 3). In the normal state, both grids are under great negative ~~tension~~ bias - namely, voltages e_{c1} and e_{c2} - in consequence of which the tube is closed. The tube will conduct ~~the~~ current if grid 1 and grid 2 are simultaneously supplied with positive pulses; ~~when~~ a voltage drop will then take place at the anode, and ~~which (drop)~~ will be transmitted in the form of a negative pulse (through a capacitor) further into the circuit. Thus the positive pulse at input 1 will be transmitted to the output circuit just when the valve (tube) is opened by a control pulse that is supplied at input 2; that is, such a tube carries out the logical operation "both... and" (at the output ~~appears a~~ a pulse appears only when the pulse u takes place at grid 1 and at grid 2). The valve circuit is often realized with the aid of diodes (two-element tubes). Figure 4 represents such a valve circuit which consists of a binary diode (for example, 6Kh6) and resistances R_2 and R_3. A control pulse is supplied to AB, namely from the point A to the point B. In the absence of a control pulse, the input pulse, by proceeding through resistance R_1 is practically short-circuited through one of the diodes depending upon the polarity of the pulse and does not strike the output busbar. In the presence of a control pulse in AB, a current proceeding through R_2 and R_3 creates in the anodes of the diodes a large negative displacement relative to the cathode, in consequence of which they seem to be nonconducting and the input pulse without being shunted enters the output busbar. Besides the diodes one can use solid rectifier elements (germanium) (Figure 5); whereupon the circuit becomes very small.

Another valve (tube) circuit which creates a pulse at the output upon the simultaneous presence of positive pulses at three inputs (logical operation is "and ... and ... and") is shown in Figure 6. Here, when pulses are absent at the three inputs, all the diodes conduct a current, in consequence of which the grid of the triode is under a low potential and it is normally closed. Such a state will exist all the time, as long as one diode will conduct current. In the case of a simultaneous supply of positive pulses to all the cathodes of the diodes, the latter ones are closed, the potential of the grid sharply increases, and a positive pulse appears at the output.

Let us consider one more elementary circuit of electronic machines, the so-called "separator" circuit. The problem of the separator circuit is this: having several input lines, connect them with the output lines without connecting them among themselves (leaving them "separate"). Whereupon each of the input lines can transmit a pulse only to the output line, but not to any input line. The pulse in the output line can be transmitted either from the input of No. 1 or from the input of No. 2 (the logical operation is "either ... or").

The simplest separator circuit which consists of a binary triode with a total anode load (resistance R) is represented in Figure 7. The input pulses are supplied to the grids of the triodes and are transmitted unimpeded to the anode circuit; however the input lines themselves are not connected among themselves.

Another separator circuit with three inputs is shown in Figure 8. With the absence of pulses at the inputs, all the diodes are closed and the grid of the right triode is under great positive potential and, consequently, they conduct a current. When a negative pulse is supplied to any of the inputs, the corresponding diode becomes conducting, in consequence of which the potential of the triode's grid sharply drops, the latter is closed, but the potential of its anode increases suddenly, creating at the output a positive pulse. It is easy to see that in this circuit scheme all three input lines are separate. Here also besides the diodes one can use germanium rectifiers. The three forms of elementary circuits discussed are the fundamental "bricks" (units) from which one constructs the most complicated calculating and control circuits of electronic machines. In the following paragraph we shall show how circuits for the execution of mathematical operations are composed of these indicated elements.

2. 4. Counter Circuits

As we shall see below, the basic operation in electronic mathematical machines is addition. All remaining mathematical operations - subtraction, multiplication, division - are reduced in one way or another to this basic operation. Consequently, we shall begin with a discussion of counter circuits that execute the addition operation, or, as they are called for short, 'counters'.

In electronic machines that compute according to the decimal system, the counters (counter circuits) operate according to the principle of 'simultaneous ordered calculation' (parallel operation). The individual category of a counter (so-called 'counter ring') is the elementary counter circuit for the addition (or subtraction) of one-place (single-valued) numbers. First the ciphers of the categories are added up simultaneously and in order. If as a result of addition in any of the categories there must occur a 'carry-over' of a ten to the following category then this is remembered and the process is carried out at the completion of ordered summation. The counter ring of each category is joined, with the aid of its conductor, at the proper time to the counter ring of the corresponding category of another counter circuit and receives ('perceives') the cipher of the given category in the form of electrical pulses; whereupon the number of pulses correspond to the perceived cipher (for example, the cipher 6 corresponds to six pulses, etc). For the present we shall set aside the question of how these pulses are formed, but we shall discuss the process governing their reception and summation. A strictly counter ring of one category without supplementary 'carry-over' circuits, subtraction, etc. consists of ten memory cells joined in a ring so that the left static output of each preceding cell is connected through a separater capacitor of 50 micro-micro F ($\mu\mu F$) to the left input of the following cell. All these cells are numbered by the ciphers 0, 1, 2,.., 9 (see Figure 9). The normal state of a memory cell will be considered that for which the right tube conducts a current and the left does not. The opposite state will be called excited. In Figure 9 all the memory cells, excluding the zero cell, are in the normal state. The excited state of the zero cell can be observed visually in the form of a glowing neon lamp corresponding to the cipher 0. Thus, in the counter ring represented in Figure 9 the cipher 0 is established (the category is erased).

In the memory cell of our counter ring the input 'throwing-over' pulses are supplied not from the network side but from the cathode side; here, a negative pulse at the cathode is equivalent to a positive pulse at the grid. All input terminals of the right tubes (cathodes) are connected together and form the input line of a counter ring. Then, feeding a negative pulse to this input line is equivalent to feeding a positive pulse to the grid of all right tubes. We assume that all cells are in the normal state and only one is in the excited state (the cell under number 0). Then, an impulse that is fed to the input line acts only upon that cell which is in the excited state, by 'throwing over' the cell to the normal state. (Note: This pulse does not affect the cells that are in the normal state; therefore, a positive pulse that is supplied to the grid of the conducting tube does not change the state of equilibrium of a cell). Here, a positive pulse arises in the left static output of this cell; this pulse is transmitted to the grid of the left tube of the following cell and 'throws over' the cell to the excited state. Thus, the arrival of each subsequent pulse to the input line transfers the state of excitation to the cell of the following number (to the following stage). If now we agree that the number of the excited stage shall signify a cipher that is set up in the counter ring, then the arrival of each subsequent pulse will correspond to the addition of a unit to the cipher set up. The arrival of three pulses will correspond to the addition of the cipher three etc. During transfer ('carry-over') as a result of the addition of ten, the supplementary circuit (see below) 'perceives' the need for carrying over, and the same counter ring is set in correspondence with the cipher of units of the ring is set in correspondence with the cipher of units of the obtained two-place (double-valued) numbers. For example, let the counter ring remain on cipher 6 (in the excited state the cell is found under number 6) and at the input let 7 pulses be supplied. Then the counter circuit goes through successively the stages 7, 8, 9, 0, 1, 2 and remains on the 3-rd stage (6 + 7 = 13). However, during transfer of the excited state from stage 9 to stage 0 the need for transfer (carry-over) is 'detected' by the supplementary circuit, which (transfer) is thereupon effected. In order to observe the operation of a counter ring at the right static output of each stage one can connect in the circuit a small neon lamp which will glow whenever the given stage is in the excited stage. Thus, the number of the glowing lamp indicates what number is established in the given counter ring.

Above we have assumed that at each moment (in this number also the original one) only one cell of the counter ring is found in the excited state. This ensures the ability to assign to the grid of tubes a constant negative voltage which determines the operating regime (state) of the tubes (grid bias). This negative voltage is created by connecting a special bias resis tance to the cathode circuit, the voltage fall in which (resistance), due to the anode current in the tubes, also creates a negative potential of the grid relative to the cathode. However, in ~~a~~ the cathode circuit of the left tubes a large bias resistance is connected (19700 ohms compared to 1640 ohms for the right tubes, in consequence of which only one left tube can ~~simultaneously~~ conduct current at any given instance (that is, only one cell can be excited), since the grid bias, even ~~already~~ for two conducting tubes would be ~~seems~~ so large that all the left tubes would be cut off.

The extreme left tube (in the input, Figure 9) is an inverter (6L6). Its job consists of converting the incoming positive impulses to negative before feeding them into the input cathode line. In the normal state the tube is closed and, therefore, its anode potential is high. When a positive impulse is fed to the grid of this tube it begins to conduct a current, whereupon the voltage on its anode sharply falls: that is, a negative impulse is created.

The tube 6U6 (in the lower right-hand corner, Figure 9) serves to extinguish the counter ring; that is, to set it at zero. The anode of this tube is connected with the grids of the right tubes of all the stages 1-9, with the exception of stage 0, where it is connected with the grid of the left tube. The grids of all the remaining tubes are connected across 1200 ohms resistence with the cathode of tube 6U6 (through the common terminal 85b). In the normal state the tube 6U6 conducts a current, and because its internal resistance is approximately equal to 1200 ohms, then the grids of all the tubes possess an identical grid bias. In order to extinguish the counter ring a negative "extinguishing impulse" is fed to the grid of tube 6U6. The tube is closed, with the result that its anode potential suddenly rises. Then the grids of the right tubes of stages 1-9 and the left tube of the 0 stage receive a positive impulse which puts stage 0 in the excited state and all the rest in the normal state: that is, the counter will be extinguished.

The static outputs of the right tubes of all stages of the counter ring, called the static outputs of the individual stages, lead out from the counter ring and serve (in the case of necessity) for the static transmission of ciphers accumulated in a given category (see below about the electronic table of multiplication).

Before passing on to a further consideration of the operation of a counter, as, for example, the carrying over of tens, the transmission of numbers from one counter to another, etc., let us briefly investigate the system of impulses which direct the operation of the electronic machine.

Depending on the type of operation of the machine (in parallel or in series), on the system of memory, and on the synchronization, the operations of the whole machine are based on this or that system of impulses, produced by a special generator. As an example let us examine the system of impulses on which the operation of the above described counter is founded. The impulse-generator creates several series of impulses, repeated every 200 microseconds (the machine's cycle of operation). Each of these series is transmitted on its own individual lead and passes through the valve device at the proper moment into these or those circuits. In the course of one cycle one elementary operation can take place in each block, such as: addition, subtraction, or transmission of a number. The whole cycle is split into 20 intervals of 10 microseconds each. The first ten intervals serve for the orderly arithmetical actions (addition, subtraction, transmission of numbers), and the second ten intervals for the auxiliary operations - carrying over of tens, extinguishing of the counters, changing of the connection with the aid of the reversal of the valve tubes, etc. Spacing of the separate series of inpulses over the intervals of a cycle is represented in Figure 10. In this figure the intervals of the cycle are plotted on the horizontal axis, and the individual series spaced on the vertical. The purpose of each separate series of impulses will be explained below, but in the meantime let us note that all the impulses (aside from the long impulse controlling the valves of transmission) are about 2.5 microseconds in length, and the minimum interval between them is equal to 10 microseconds.

Let us now break down in detail the operation of one category of the counter, the skeleton diagram of which is represented in Figure 11. In each counter there are ten such categories for the remembering of a ten-place number and one binary category (the normal memory cell) to fix the sign. The individual stages of the counter ring are represented in the form of half crosshatched rectangles, numbered from 0 to 9. The ring is shown in that condition which exists when the ninth stage is in the excited state: that is, in this category the number 9 is specified. Let our counter in the course of the given cycle be made to perceive a certain number. Then the program impulse in the seventeenth interval of the preceding cycle (Figure 10) throws over the memory cell (see below on program control), which controls valve 2 (Figure 11); the latter finds itself in the "on" state and connects our counter ring to the line of the corresponding category of the numerical busbar during the given cycle. The impulses entering from the busbar pass through tubes number 3, 4, and 5, designed to correct the form of an impulse ("impulse-standardizer"), and pass through the inverter type 6 (tube 6L6 in Figure 9) into the common input of the counter ring. Here the counter ring "turns" to the number of stages corresponding to the number of perceived impulses. If the state of excitation of the counter ring during this "turn" passes from the ninth to the zero stage (for example, 8 + 5 = 13), then a carrying over of one to the ring of a higher category must take place. However, this carrying over cannot be accomplished immediately, since at this time the ring of the higher category is also receiving impulses from the numerical busbar. The fact of carrying over is remembered in that it was accomplished between the eleventh and seventeenth intervals of the same cycle. It is carried out in the following manner. The static output of the ninth stage controls the valve 7, one of whose inputs is connected to tube 5 of the input circuit.

When the counter ring "decides" on the cipher 9, valve 7 opens, and the following impulse from the numerical busbar, shifting the ring from the ninth stage to the zero, passes also valve 7, tube 9, and throws over the memory cell of carrying-over (tubes 11-12). Here valve 8 of carrying-over opens. True, the impulse from valve 7 also enters through inverter tube 22 to valve 24, however here it is cut off, since valve tube 24, controlled by impulse CCG (Figure 10), is closed up to the 11th interval. In this way, as a result of the shift of the counter ring through ten, to the eleventh interval, the memory cell of carrying-over (11-12) is thrown over, and the valve of carrying over 8 is opened. As concerns the counter ring, the category of ones as a result of addition is left behind in it (in the example 8 + 5 = 13 the counter ring is set on the cipher 3).

The actual carrying over takes place between the eleventh and seventeenth intervals. For the duration of this fragment of time the long impluse CCG enters from the generator, opening valves 23 and 24. In the thirteenth interval the first impulse of carrying over RP (Figure 10) passes through valve 8, inverter tube 21, valve of carrying over 23, and enters the input line of the following, higher category, moving it to one. This same impulse, passing through valve 8, also enters tube 10 and throws over the cell of carrying-over (11-12) to its original state: that is, it prepares the system for the next cycle.

One such carrying-over can call forth another, the second a third, etc., for if the category receiving the impulse of carrying-over is already set at 9, then a further carrying-over must take place. This is accomplished with the aid of tubes 7, 22, and 24. Let us assume, for instance, that the counter ring (Figure 11) is set at 9 when an impulse from the nearest category on on the right enters the impulse-standardizer. Since the counter ring already stands at 9, then valve 7 is opened, and this impulse (beside the fact that it carries over the given counter ring from 9 to 0) passes through tubes 7, 22, and 24 to the following category. (Note: This impulse also throws over the cell of carrying-over (11-12). However, the latter returns to its original state after the second impulse RP, entering valve 8 in the nineteenth interval (see Figure 10).)

The necessity of such successive carrying-over explains why the impulse which opens the valves of carrying-over (23, 24) must last 50 microseconds after the first impulse RP causes the carry-over. In the most unfavorable case twenty successive carryings-over must take place. Let us consider, for example, the addition of + 1 and - 1 on a twenty-place counter (the coupling of two ten-place counters). The negative number -1 is stored in the form M 99,999,999,999,999,999,999 (in the form of addition to 10^{20}, where M signifies that the binary counter of sign registers "minus". If + 1 is added to the number contained in this counter, then one impulse will be sent into the unity category and none into the other categories. One impulse, entering the unity ring, shifts it from 9 to 0 and throws over the carrying-over cell (11-12) of the unity category. When the execution of carrying-over begins, the first impulse RP passes through tubes 8, 21, and 23 of the unity category into the ten category; since the ten category already stands at 9, then it (the impulse) shifts it to 0, and through tubes 7, 22, and 24 of the ten category passes into the hundred category, etc. This process is repeated on the whole twenty times, until the indicated impulse has shifted the ring of every category from 9 to 0 (except for the unity category, already standing at 0), and the binary counter of sign from M to P (plus), thus leaving the numbers 0 (1 - 1 = 0) in the counter. Experimental research has shown that 25 microseconds are necessary for the complete twenty-fold carrying-over. With a reserve coefficient of 1:2, 50 microseconds are set aside in each cycle for this carrying-over.

Further, let us, examine the process whereby a number is transferred from one counter to another. Here the task consists of converting the static representation of a number located in a decimal ring into the dynamic, impulse form. If it is necessary to transmit a number for addition, then the number of impulses going out through tube 16 is equal to the cipher contained in the counter ring. If it is necessary to transmit a number for subtraction (which is executed in the form of addition of the number, supplementary to the given to 10^{20}), then the number of impulses going out of the counter ring through tube 15 and the separator circuit is equal to the difference between 9 and the cipher contained in the counter ring. (Note: Here in each category addition is carried on up to 9. In order to obtain the number supplementary to 10^{20}, it is necessary to add one more impulse to the output busbar of the unity category, this impulse being called the supplement impulse. A special impulse, sent into the unity category, into the tenth interval, serves in this capacity (impulse 1'P - see Figure 10).). Thus each category of the counter possesses two outputs: the output of subtraction and the output of addition.

For the transmission of a number from the counter ring a series of ten impulses - 10 P (Figure 10) - is employed which is introduced into the counter ring through the separator tube 1 (Figure 11). These impulses "turn" the ring a full revolution through 9 and 0 to that value on which it was earlier located. For example, if the cipher 3 was set in the ring, then through the action of the 10 P impulses the ring passes through 9 and 0 and again stands at 3. With the shift of the counter ring from 9 to 0 the memory cell of carrying-over (11-12) is thrown over. In our example this takes place during the sixth interval. Before the cell of carrying-over was thrown over the valve of subtraction (tube 13) was open, but after the throwing over the valve of subtraction is closed and the valve of addition (tube 14) is opened. Thus in our example the valve of subtraction is open from the middle of the zero interval to the middle of the sixth, and the valve of addition from the middle of the sixth to the middle of the ninth. Consequently, if in the course of the given cycle a series of nine impulses (series 9P in Figure 10) is applied to the valves 13 and 14, then six impulses of this series will pass through the output of subtraction and three impulses through the output of addition: that is, from the output of addition we will receive in impulse form the number stored in the counter, and from the output of subtraction its supplement. The counter ring itself remains in its original condition. We notice that when the number is transmitted from the counter the circuits of decimal carry-over are disconnected, and that this can be accomplished through shutting off (by means of a valve) of the impulse CCG from the counter ring. At the end of the transmission of the number the cell of carrying over (11-12) is returned to its original state by the impulse RP (Figure 10). The output cipher impulses are transmitted through the separator circuits to the lines of the numerical busbar.

Further, let us consider another principle in the construction of a decimal counter. We will construct each category and, consequently, each counter ring from four memory cells connected in series which will be in essence a four category binary counter. For this we do not make use of the full "capacity" of such a binary counter, for it is able to represent numbers from 0 to $2^4 = 16$, but only part of its possibilities, since it is sufficient for us to possess representations of numbers only from 0 to 9. The circuit diagram of one counter ring (one category) of such a counter is represented in Figure 12.

Input impulses are fed to the resistance R of the first memory cell (first stage). When the counter is in the extinguished state, that is, the cipher 0 is set, all the right tubes conduct current, while all the left tubes do not conduct. Consequently all neon signal lamps are extinguished, and if the given ring is to be considered as a four category binary counter, then the number (0000) is set on it. An entering negative impulse across resistances R_1 and R_2 is fed to both grids of the first cell. Hereupon the first cell is thrown over into the excited state, that is, the left tube of this cell begins to conduct current, the plate potential of the right tube rises, and the first neon bulb lights up - the number (0001) set in the counter. On the entry of a second pulse into the input the first cell is thrown back over into the normal state, and the negative impulse created as a result of the drop in grid potential of the left bulb passes through the capacitance into the second memory cells, throwing it into the excited state - the number (0010) is set in the counter. The third impulse brings our system into the state (0011), etc. Thus the circuit actually operates as a four category binary counter whose input impulses (numbers) are fed only into the unity category, and not into all four categories simultaneously. This guarantees that in such a series connection of memory cells each successive cell receives an impulse only when the preceding cell has changed from the normal state to the excited and then back again to normal; that is, has executed the two operations of the binary system: $0 + 1 = 1$; $1 + 1 = 01$ (into the following category).

In the realization of this circuit it is necessary to take $R_2 \gg R$ in order that the input impulse in practice enter only the first cell, the impulse from the first only the second, etc.

Moreover, since the input impulse is fed immediately into both grids of the memory cell, for the definitiveness of the change from one stable state to another the duration of the input impulse must be less than the duration of the internal crossover impulse from the plate of one tube to the grid of another (this impulse properly throws over the system). In the contrary case a lingering input impulse will maintain both tubes in a nonconducting state (a state of unstable equilibrium), whose output at the end of the input impulse will be indeterminate. The duration of the input impulse is determined by the time constant of the input circuit RC, and in order to guarantee the above specified case, we must take

$$RC < \frac{1}{5} \cdot R_3 C_3$$

Since the circuit pictured in Figure 12 appears as a counter category of a counter constructed according to the decimal system, it must possess circuits compelling it to return to the original position (0000) after receiving the tenth impulse and it must send the impulse into a carrying-over circuit. This i s accomplished by the two cross connecting lines shown in Figure 12 by the broken lines. (Note: We will notice that in the absence of such special compelling circuits our circuit would carry out the indicated operation only after receipt of the sixteenth impulse, since $2^4 = 16$). Before receipt of the tenth impulse the counter ring is in the state (1001), that is, the first and fourth cells excited, while the second and third are in the normal state. On receipt of the tenth impulse the counter ring changes back to the normal state and through capacitance C changes the second cell to the excited state (although actually this does not take place ~~due to~~ because of the "contrary" impulse entering from the cross connection, see below), and through capacitance C_a of the supplementary circuit transmits a negative impulse to the grid of the left tube of the fourth cell. This impulse changes the fourth cell to the normal state, whereupon a negative impulse enters through capacitance C_5 into the circuit of carrying-over (in the following category). With the change of the fourth cell into the normal state a positive impulse moves through capacitance C_6 and the cross connecting line (broken line) to the grid of the right tube of the second cell, preventing the change of the second cell to the excited state after receiving the negative impulse from the first cell. Thus after the arrival of the tenth impulse the counter ring is set in the position (0000), and through capacitance C_5 one impulse of carrying-over will be transmitted.

The values of the capacitances C_a and C_b, and also the separator R_6 are so selected that these supplementary circuits do not interfere with the normal count of the category from 0 to ten. The machine we have obtained is completely equivalent in its external characteristics to the one that we examined earlier which was composed of ten memory cells. However here we obtain a substantial economy in tubes (by 2.5 times). Concerning the circuits of carrying-over, the determination of a number, the formation of the supplementary number, etc., it is possible to apply all the same circuits that are employed in counter rings with ten cells.

Further, let us examine counters which operate on the binary system. The ciphers of the binary system (0 or 1) appear in electronic machines as the presence (1) or absence (0) of an electric impulse. In parallel operating counters (where all ciphers of a given number are fed simultaneously into their own counter categories by separate busbars) each category represents one memory cell. One stable state corresponds to the cipher 0, the other to the cipher 1. In this counter (as in other parallel operating counters) the whole operation of addition consists of two parts - basic addition and the carrying-over of "tens". Basic addition consists of the change-over of the counter category (cell) under the influence of an incoming impulse (which is the only significant cipher of the binary system) from one state to the other. If the cell stands at 0, then we get 0 - 1 = 1, while if it stands at 1, then 1 + 1 = 01 (into the carrying-over circuit). Concerning the operation of carrying-over, it may be accomplished by two methods. The first method is the same one used in the decimal system counter described above. The carrying-over is produced by a special carrying-ever impulse passing through all categories of the counter where a system is employed which is analogous to "nine warning" in the decimal counter, with the result that if carrying-over originates in the preceding category, but the category considered already stands at 1, then the carrying-over impulse enters not only the category considered, but also the following (compare valves 7, 22, and 24, Figure 9).

The other system consists of the presence of two more carrying-over counters in addition to the basic counter. In the first cycle the operation of basic addition takes place; the carryings-over originating then are

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stored in the first carrying-over counter. Then the number of carryings-over from the first counter enter the main counter in the form of items; the carryings-over originating at this time are stored in the second carrying-over counter. After this the number of carryings-over from the second counters are fed in the form of items to the main counter, and carryings-over are stored anew by the first counter, etc. until both carrying-over counters are extinguished.

The carrying-over circuit can be significantly simplified if the consecutive operation system of the binary counter is employed. The system of consecutive operation consists in the carrying out of ordered addition not simultaneously, but successively, category after category, beginning with the lowest. Then the circuit of the binary counter will possess the form represented in Figure 13. At first addition takes place in the unity category. After the cell of the unity category has changed into a new stable state the carrying-over impulse (if it takes place) enters the decimal category through the capacitance C and the separator diode (germanium), etc. Addition to the following category (decimal) must not begin before the cell ~~of this cell~~ of this category has changed into the stable state; that is, in consideration of the possibility of carrying-over, the impulse in the busbar of the following category must lag behind the impulse of the preceding by a time not less than $2\Delta T$, where ΔT is the duration of the memory cell's change over from one stable state to the other. If we have a thirty-place binary number (which corresponds to a ten-place decimal), then the impulse in the busbar of the highest category must lag behind the impulse in the unity busbar by not less than 240 microseconds (if we take the damping time of the cell to be 4 microseconds). Here, as we can see, the carrying-over can be accomplished in the process of addition and lot isolated into a separate operation. The rectifying elements shown in Figure 13 serve the purpose of separating the circuits so that, for example, a negative impulse fed to the decimal category is not transmitted to the unity category, etc. Concerning the necessary time difference between impulses transmitted through the various categories' busbars, if a number is fed into the counter from a dynamic memory device (see below), then this difference can be obtained automatically in the element of the memory itself; but if the number is fed from a static device (for example, from another counter of the same type), then the necessary time difference can be obtained through the employment of special retarding lines through which impulses pass not instantaneously, but in the course of a given time interval.

The system of consecutive operation has become wide-spread in the purely dynamic systems, in the so-called dynamic devices the numbers (ciphers) are represented only as successive impulses, and not as a system of static state (static representation, compare memory cells). Such a series of impulses can circulate in the special elements of a dynamic memory, survive indefinitely, and then be summoned into the counter, when necessary, to carry out an arithmetic operation on a number, the result of which operation can be sent back to the memory element. In Figure 14 is shown the dynamic representation of a number in the binary system. The whole number (ciphers of all categories) is transmitted on one lead in the form of a series of impulses. In the latter systems they obtain a difference (in time) of 0.5 microseconds between the ciphers of different categories, and the breadth of each impulse is a little less than its amplitude. Corresponding to unity in a given category is the presence of an impulse in this category's place (in time), while zero is represented by the absence of an impulse, during which the progress of the categories is from left to right (unity in the very left hand spot). Thus an eight-place binary number is allocated an interval of time equal to 4 microseconds. Individual numbers are separated one from another by broad marking impulses. In Figure 14 is represented the number 1101011 or 235 in the decimal system.

Let us have two leads through which components, in the form of series of impulses, are fed, and we must obtain on a third lead a series of impulses corresponding to the sum of these numbers and direct the latter to the dynamic memory element. Before building the skeleton circuit of such a counter out of elements already known to us, let us examine the general character of the operations which it must fulfil. The counter in general possesses three inputs and two outputs (Figure 15). Through one output, for example A, one component is fed, and through another, B, another component, both fed in such a way that the impulses representing the lower categories enter first. The counter must operate in such a manner that when an impulse is present at a given moment on busbar A or busbar B an impulse will appear in the output busbar D. When there are impulses simultaneously present on A and B (operation 1 + 1 = 01 and carrying-over to the next category) there will be no impulse on basbar D, whereas there must be an impulse on output busbar C (a carrying-over impulse) which, after passing through the retarding line in 0.5 microseconds, is fed into C (the input of carrying-over) at the same moment that the impulses of the following, higher category are fed into the input busbars A and B. In the sense of the operation of the machine input C (carrying-over) is equally as important as inputs A and B. Therefore the entry of the impulse into input C at the time of the following category is equivalent to adding one to this category, that is, the execution of the carrying-over operation. In all the counter must execute eight possible combinations (see table).

The specified possible combinations can lead to the following arithmetical operations:

1. One impulse on any one input produces as a result one impulse to the output busbar but produces no carrying-over impulse (1 + 0 + 0 = 1).

2. Impulses on any two inputs do not produce an impulse on the output busbar, but create a carrying-over impulse (1 + 1 + 0 = 0 and carrying-over).

3. Impulses on all three inputs create an impulse on the output busbar and an impulse of carrying-over (1 - 1 - 1 = 1 and carrying-over).

We can express the three possible arithemetic operations executed by the counter, adduced, through the logical operations "both . . . . and", "either . . . . or", "and . . and . . and", which can be correspondingly performed by valves and separator circuits:

1. (A and B) or (A and C), or (B and C) produce the carrying-over impulse (this corresponds to arithmetic operation number 2), but produce no impulse on busbar D.

2. A or B or C produce an impulse on the output busbar only if none of the "and" cases of the preceding point take place. In the contrary case this combination "and" closes the valve, opening the output busbar.

3. A and B and C produce an impulse in the output busbar and an impulse of carrying-over.

Having in view the necessity of applying the above adduced logical operations with the counter, we will set up its skeleton circuit from elementary valve and separator circuits (Figure 16). To carry out operation (1) we will feed the inputs A, B, and C into valves number 1, 2, and 3, applying (A and B), (A and C), (B and C). The operation "or" between these braces is accomplished through separator circuit 4, whose output is fed into the output carrying-over line C. Logical operation (2) is carried out by separator circuit 6; the output of this circuit is fed into the output busbar D through valves 7, 8, 9, and the separator circuit 10. The presence of the closing valves 7, 1, and 9 is called forth by the necessity of not allowing the impulse from separator circuit 6 into the output busbar, if some one of the combinations (A and B), (A and C), or (B and C). For this the outputs of valves 1, 2, and 3 are connected through inverter tubes (not shown in the skeleton circuit for simplicity) with one each of the inputs of valves 7, 8, and 9, which are closed in the presence of an impulse on the output busbars of valves 1, 2, or 3. The last logical operation (3) (A and B and C) is applied by valve 11 (with three inputs), whose output impulse is fed through separator circuit 10 to the output busbar of the counter. Moreover, an impulse of carrying-over will take place in busbar C, since when (A and B and C) takes place, (A and B), (A and C), (B and C) automatically takes place.

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[Figures referred to are available in CIA in the original document]

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